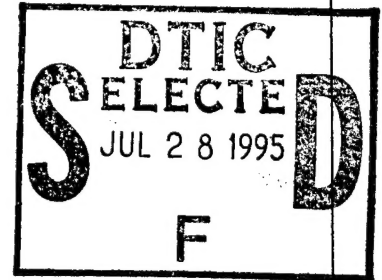# PROTON EXCHANGE MEMBRANE FUEL CELL DEVELOPMENT

WITH LIGHTWEIGHT COMPONENT MATERIALS

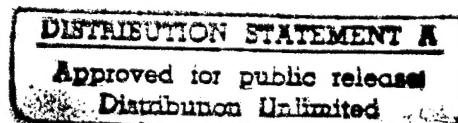## FINAL REPORT FOR PHASE 1

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Lightweight Component Materials

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Proton Exchange Membrane Fuel Cell Development with Lightweight Component Materials

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Although the Proton Exchange Membrane (PEM) fuel cell is a leading candidate for an automobile power source through meeting the zero emission requirement, its power density is currently an order of magnitude below the 400 W/kg criterion proposed by the Department of Energy. The major contributors to stack weight are the bipolar gas distribution plates. This effort, performed jointly by Energy Research Corporation (ERC) and Texas A&M University (TAMU), focused on lightweight alternative bipolar plate materials and designs. The electronic conductivity of various candidate materials was evaluated. The emphasis was on conductive plastic materials and porous graphite. Several plastic materials with specific resistance between 0.5 and 0.8 ohm/cm were identified. Preliminary evaluation of lightweight materials was performed in single cell tests. The emphasis was on atmospheric pressure and internally humidified cell operation as a potential means of system simplification and reduction of PEM fuel cell ancillary equipment complexity and weight. The performance of single cells was nearly the same at 1 and 3 atm pressure. At a cell potential of 0.6V, a current density of 230 mA/cm^2 was reached at 1.7 stoichiometric air flow rate. With lightweight bipolar plates, the DOE power density target may be achieved with unpressurized, internally humidified cell stacks.

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ENERGY RESEARCH CORPORATION
DAAH01-94-C-R184 FINAL REPORT

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1.   INTRODUCTION

This report summarizes the research performed under Contract DAAH01-94-C-R184 to the U.S. Army that constitutes the Phase I effort toward Proton Exchange Membrane Fuel Cell Development with Lightweight Component Materials under the Technology Reinvestment Project, Topic Number TRP 93-024. The work was performed jointly by Energy Research Corporation (ERC) and Texas A&M University (TAMU).

Although the Proton Exchange Membrane (PEM) fuel cell is a leading candidate for an automobile power source through meeting the zero emission requirement, its power density is currently an order of magnitude below the 400 W/kg criterion proposed by the Department of Energy. The major contributors to stack weight are the bipolar gas distribution plates. This Phase I effort focused on the electronic conductivity of lightweight alternative bipolar plate materials and preliminary evaluation of their performance in single cell tests. The emphasis was on atmospheric pressure and internally humidified cell operation as a potential means of system simplification and reduction of PEM fuel cell ancillary equipment complexity and weight.

2.   TECHNICAL BACKGROUND

2.1   Rationale and Performance Criteria for Electric Vehicles

The incentive to develop electric vehicles is rapidly growing as a result of legislation passed in California calling for the introduction of zero emission vehicles by the year 1998. In order to meet these emission requirements, vehicles must be powered by batteries, fuel cells or hybrid fuel cell/battery power sources. After the oil embargo in 1973, several projects were initiated by the U.S. Department of Energy to develop and demonstrate advanced battery power sources for electric vehicles. Although projects on several types of advanced batteries have been carried out for more than twenty years tough challenges still remain, i.e., enhancing the energy density to successfully compete with internal combustion engines and increasing the vehicle range.

The U.S. Department of Energy (DOE) has proposed certain criteria for electric vehicles: a power density of 400 W/kg and an energy density of 200 Wh/kg. The best way of demonstrating the power and energy densities for power sources of vehicles is the Ragone Plot(1) shown in Figure 1. It is clear from this figure that batteries (energy storage devices) have fixed and relatively constant energy densities and variable power densities. Energy conversion devices such as fuel cells, however, are similar to internal combustion engines with relatively constant power densities and variable energy densities. In order to successfully compete with internal combustion engines, the power density of electrochemical power sources must increase.
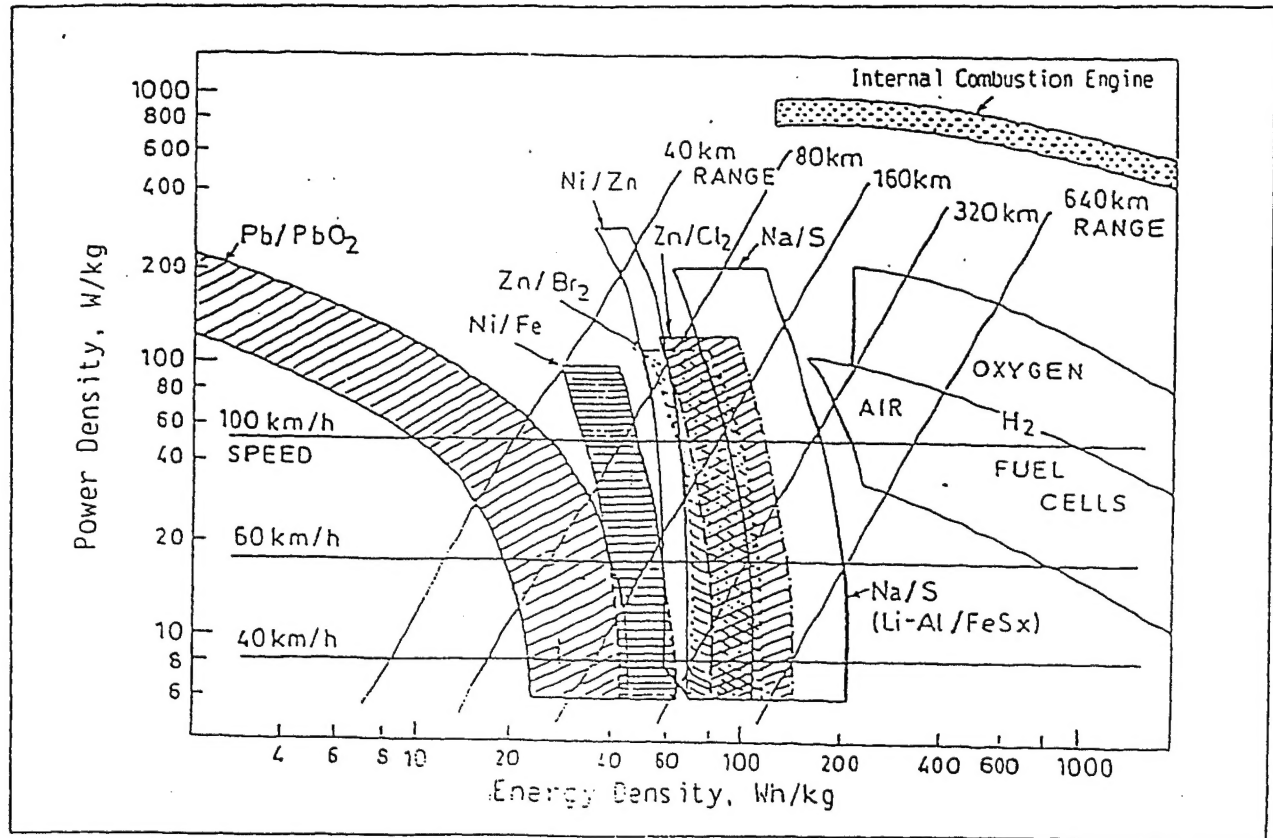
FIGURE 1
**RAGONE PLOTS FOR ELECTRIC AND INTERNAL COMBUSTION
ENGINE POWERED VEHICLES:**
Overlaid grids indicate speeds and performance range of vehicles.

2.2 Proton Exchange Membrane Fuel Cells: The Leading Candidate Power Source for Electric Vehicles

The Fuel Cells for Transportation Program, sponsored by the DOE, began in the late 1970s at Los Alamos National Laboratory and Brookhaven National Laboratory. A workshop, held in 1977 at Los Alamos National Laboratory, and attended by representatives from industry, government, and university laboratories resulted in several studies on the most promising types of fuel cells and fuels for electric vehicle applications(2). Several techno-economic assessments based on available fuel cell performance lead to the conclusion that the leading candidate for an automobile power source is the proton exchange membrane fuel cell.

Ballard Power Systems, Inc. has made considerable progress in developing PEM fuel cells. They have built several 3-5kW units and, in December 1992, installed 24 of these stacks to make up a 120kW power plant for a bus. The 5kW fuel cell stacks each weigh about 50 kg, while the total 5kW power source unit weighs about 150 kg. The power density in this system is only about 33 W/kg, an order of magnitude lower than DOE's goal for electric vehicles. The major contributor to stack weight is the relatively thick, heavy bipolar plate. In order to bring PEM fuel cell powered electric vehicles to the marketplace, it is imperative to develop lightweight PEM fuel cell components.

Recently, some very promising results using conductive plastic bipolar plates have been obtained at Texas A&M and Globe Tech, Inc.(3) These molded plates are made with polyethylene and graphite and have a density of about 1.2 g/cm^2, as compared with about 2 g/cm^2 for carbon (graphite). Furthermore, these plates can be made relatively thin, resulting in further weight savings and a more compact power unit. Typical cell potential versus current density plots, shown in Figure 2, compares the performance of a PEM fuel cell built with graphite plates and a PEM fuel cell built with conductive plastic plates.

3. PHASE I RESEARCH RESULTS

During the six-month Phase 1 effort, ERC and Texas A&M University focused on (i) the selection and evaluation of conductive plastic materials for bipolar plates, (ii) measurements of their resistances in configurations simulating those in fuel cells, (iii) optimization of the electrode structures and membrane and electrode assemblies to improve fuel cell performance, and (iv) evaluation of cell performances in single cells with electrode areas of 5, 25 and 50 cm^2. During this Phase I research activity, efforts were also made to operate the proton exchange membrane fuel cells without external humidification. Water management in PEM fuel cells is one of the major challenges. If the fuel cells, particularly with the lightweight plastic components, can be operated without external humidification, there would be a significant advantage in being able to further reduce the weight of the PEM fuel cell stack. The work at
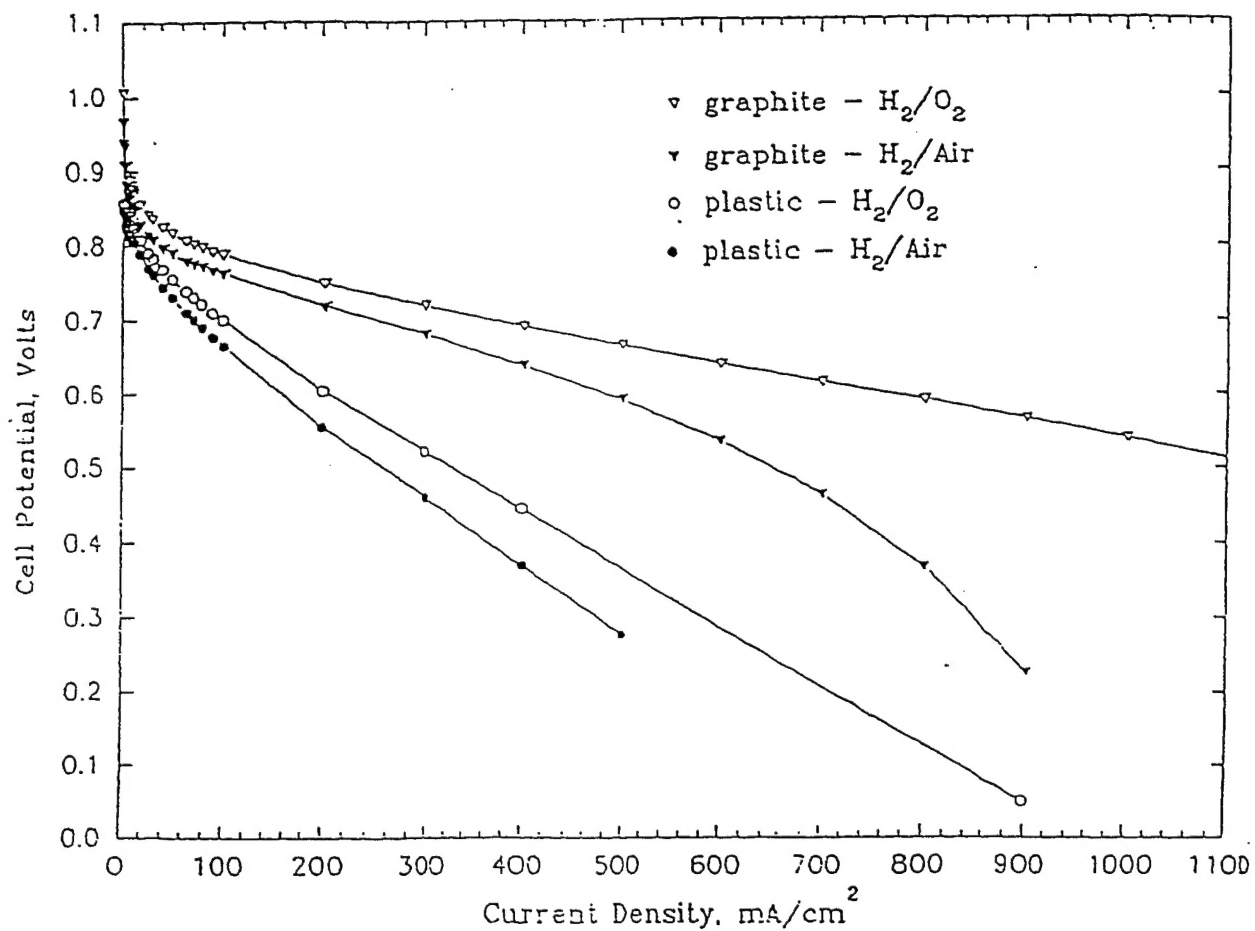
FIGURE 2
PEM FUEL CELL PERFORMANCE COMPARISON WITH
GRAPHITE AND CONDUCTIVE PLASTIC PLATES:
Previous results of PEM fuel cells with graphite and conductive plastic current
collectors containing fluid flow channels for reactant gases
shows slightly lower performance.

TAMU also consisted of furnishing ERC with membrane and electrode assemblies for tests in the single cell test fixtures developed at ERC with lightweight components.

3.1. Work Carried Out in Phase I at Texas A&M University

3.1.1 Fabrication of Conductive Plastics and Resistance Measurements

Conductive plastic manufacturers LNP, RTP, DuPont and Bekaert were contacted and material samples obtained. Physiochemical characteristics of these materials are presented in Table 1. These companies provided only ranges of values (instead of exact values) for the specific resistances. Resistance measurements were also made on the state-of-the-art conductive plastic, previously used in the alkaline fuel cell by Exxon-Alsthom(4) and in the zinc-bromine battery project by Exxon-SEA(5). The specific resistance measurements involved clamping a 5 cm^2 sample between two copper plates and passing a current through. The output voltage across the copper plates was recorded as a function of current. Various treatments were applied to the samples by the manufacturer or at TAMU to overcome the skin resistance and to improve bulk conductivity. The treatments were (i) hot-pressing of carbon cloth to the plastic surface, (ii) introducing some carbon particles within the conductive plastic, (iii) sanding or sand-blasting the surface, and (iv) application of silver epoxy to the conductive plastics. The specific resistances of these modified materials were measured. The modified materials exhibiting the lowest resistances were used for the fabrication of the proton conducting plates with the gas flow channels for the PEM fuel cell 5 cm^2 single cell test fixtures.
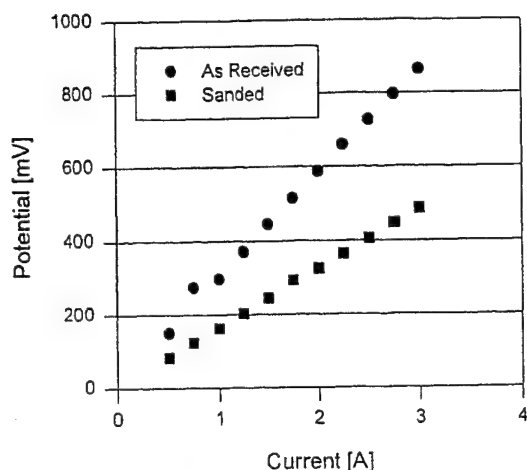
The potential vs. current data points was plotted and linear regression analyses were carried out to determine the specific resistances of the samples. Table 2 shows the values of specific resistivity for the different conductive plastics. The SEA plastic consisted of polyethylene with 40% graphite. The second sample of SEA plastic was made by hot-pressing graphite cloth on both sides to overcome the skin resistance, which thereby reduces the contact resistance. Sample 90169 from LNP is a base material of polycarbonate filled with FR stainless steel EMI-X grade fibers. Sample 88646 has a base material of ABS plastic with FR stainless steel EMI-X grade fibers. Samples 88134 and 88132 have a base material of polycarbonate with EMI-X stainless steel fibers. Sample 88134 has a higher concentration of stainless steel fibers than sample 88132. Sample 88130 has a base material of ABS with EMI-X stainless steel fibers. The sample from RTP has a base material of polyphenylene sulfide coated with nickel-chromium. The PBT series from Bekaert has a base material of polybutylene-terephthalate with glass fibers. The sample had to be sanded prior to testing due to its uneven surface texture. Figures 3(a) and 3(b) clearly show that sand-treatment of the surface lowers the specific resistances of the conductive plastic materials. According to Figure 3, hot-pressing of the carbon cloth on the RTP plastic also significantly lowered the specific resistance.

TABLE 1
PHYSIOCHEMICAL CHARACTERISTICS OF CONDUCTIVE PLASTICS:
A broad range of materials were obtained for evaluation.

Manufacturer and Sample Identification	Base Material	Conductive Filler Material	Specific Gravity
SEA plastics	Polyethylene	Carbon	1.2
Hot pressed Graphite cloth SEA plastic	Polyethylene	Carbon	N/A
LNP Conductive Plastics			
EMI-X-PDX-D-90169	Polycarbonate	Stainless Steel Fibers	1.45
EMI-X-PDX-A-88646	ABS	Stainless Steel Fibers	1.17
EMI-X-PDX-D-88134	Polycarbonate	Stainless Steel Fibers	1.42
EMI-X-PDX-D-88132	Polycarbonate	Stainless Steel Fibers	1.35
EMI-X-PDX-A-88130	ABS	Stainless Steel Fibers	1.13
RTP			
1399x66389	Polyphenylene Sulfide		1.5
BEKAERT			
PBT-Series	Polybutylene-terephthalate		1.23

TABLE 2
SPECIFIC RESISTIVITY OF VARIOUS CONDUCTIVE PLASTICS:
Sample treatment lowered resistivity from 36 to 85%.

Manufacturer and Sample Identification	Unsanded Specific Resistance ohm-cm	Sanded Specific Resistance ohm-cm
SEA plastics	5.7	3.6
Hot pressed Graphite cloth SEA plastic	2.8	N/A
LNP Conductive Plastics		
EMI-X-PDX-D-90169	6.6	4.4
EMI-X-PDX-A-88646	5.7	1.4
EMI-X-PDX-D-88134	4.0	0.6
EMI-X-PDX-D-88132	2.9	0.8
EMI-X-PDX-A-88130	13.8	4.2
RTP		
1399x66389	6.1	1.7
BEKAERT		
PBT-Series	N/A	1.8

(3a) LNP 88134 As Received Dimension: 22.14 mm x 21.09 mm x 3.25 mm
Sanded Dimension: 22.02 mm x 20.96 mm x 3.08 mm
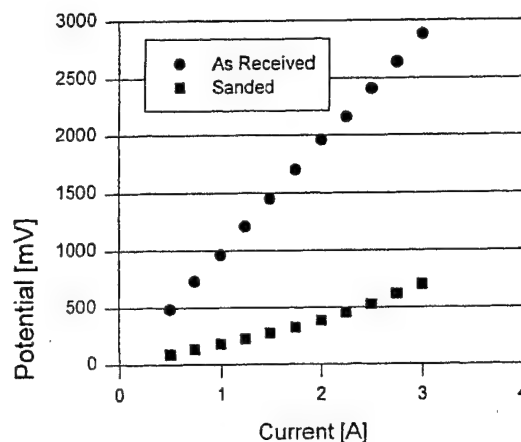
(3b) LNP 88130 As Received Dimension: 21.17 mm x 21.17 mm x 3.02 mm
Sanded Dimension: 21.15 mm x 21.47 mm x 2.62 mm
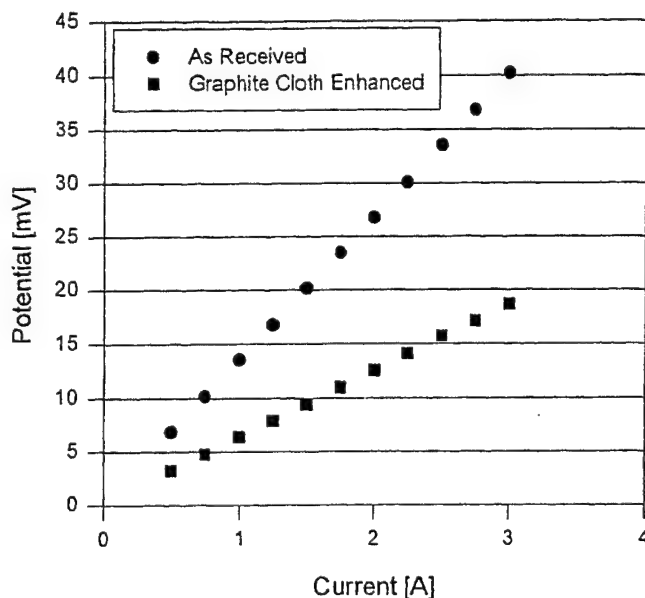
(3c) RTP as received : Radius 101.9 mm ; Thickness 3.2 mm
Graphite Cloth enhanced and Sanded Dimension: Radius 101.9 mm ; Thickness 2.88 mm

FIGURE 3
SPECIFIC RESISTIVITIES OF TREATED AND UNTREATED SAMPLES:
Plots of potential across plates versus current, recorded to obtain
specific resistances of conductive plastics, show that treated
samples have a much lower resistivity.

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Conductive plastics with specific resistivity lower than 1 Ω-cm were used to fabricate the current collector-fluid flow plates. The specific resistances of the plates were also measured in the same configuration as in the fuel cell using graphite cloth instead of the membrane and electrode assembly (MEA). This was to ensure obtaining the electronic resistance, which should be the same as during fuel cell operation. Two conductive plastics from LNP were found to have specific resistance values of 0.6 and 0.8 Ω-cm (in the small scale testing), however, there was a high contact resistance between the plastic and the MEA and further testing of these materials was suspended. The RTP conductive plastics, however, showed a consistency of the resistance values, both in the testing on the small scale and in the actual fuel cell fixture testing.

3.1.2 Structure Optimization of Membrane and Electrode Assemblies for Single Cells with Conductive Plastics

During Phase I, two directions were followed: in one, the Teflon composition of the electrode in the substrate, diffusion layer and active layer was varied. These electrodes were then hot-pressed to proton exchange membranes, set up in the single cell test fixtures and the performances of PEM fuel cells evaluated. Lower Teflon contents in the carbon cloth substrates of both electrodes and also in the diffusion and active layers of the anode improved the performance of PEM fuel cells. A lower Teflon content in the electrodes will also be beneficial for PEM fuel cells with lightweight conductive plastic plates - from the point of view of water retention in the MEA.

The second study was to test membrane and electrode assemblies, prepared by Dr. Hari P. Dhar of BCS Technology[6], in a PEM fuel cell single cell (electrode area 25 cm^2) and in a PEM fuel cell bicell (electrode area 50 cm^2). The performances of these cells without external humidification were compared with those in a PEM fuel cell single cell (containing membrane and electrode assemblies prepared using the normal procedure at CESHR) with external humidification. The results of these studies may be summarized as follows: (i) the performances in the PEM fuel cell single cells with and without humidification are nearly the same at 1 atm and 3 atm (Figure 4), (ii) at a constant cell potential of 0.6 V, there is a dependence of the current density on the flow rate of air (Figure 5). At about 1.7 times the stoichiometric flow rate, the current density reaches the highest value. However, on increasing the air pressure to 10 psig, there is an increase of performance even at 2-2.5 times the stoichiometric flow rate; (iii) in the bicell (electrode area 50 cm^2), the flow rate dependence of PEM fuel cell performance at 10 psig air pressure is observed only above 200 mA/cm^2 (Figure 6). Figure 7 illustrates the flow rate dependence at three current densities; and (iv) the lifetime studies in the PEM fuel cell bicell without external humidification reveal a stable performance at 50° and 55°C (Figure 8). However, when the temperature was raised to 60°C, even though there was a significant improvement in performance initially, there was a linear decrease in performance over a time period of nearly 300 h (decay rate $\approx$ 0.27 mA/cm^2 h). The results in the PEM fuel cell without
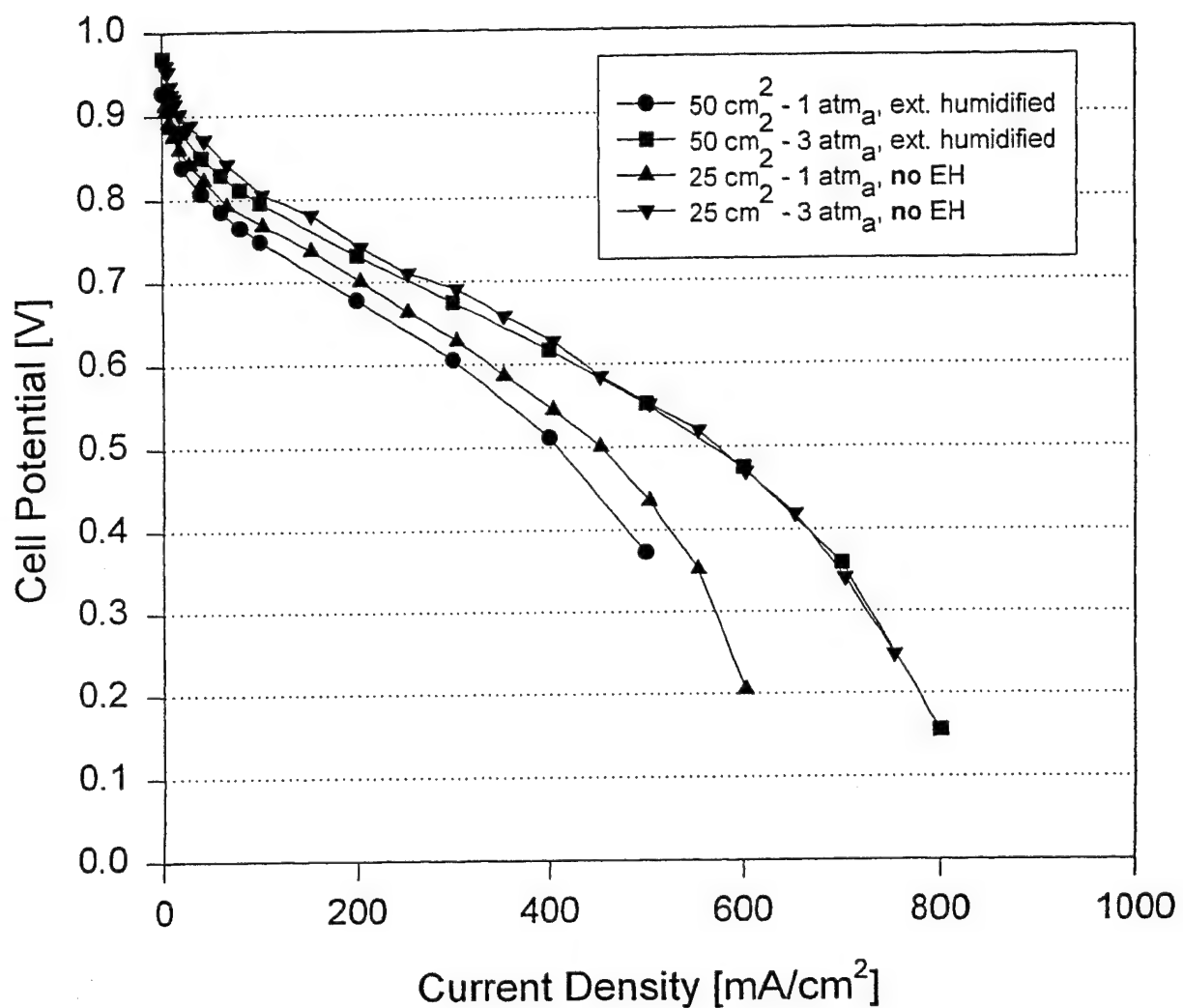
FIGURE 4
PEM FUEL CELL PERFORMANCE COMPARISON WITH AND WITHOUT EXTERNAL HUMIDIFICATION:
Fuel cell performance is not affected by remaining external humidification.
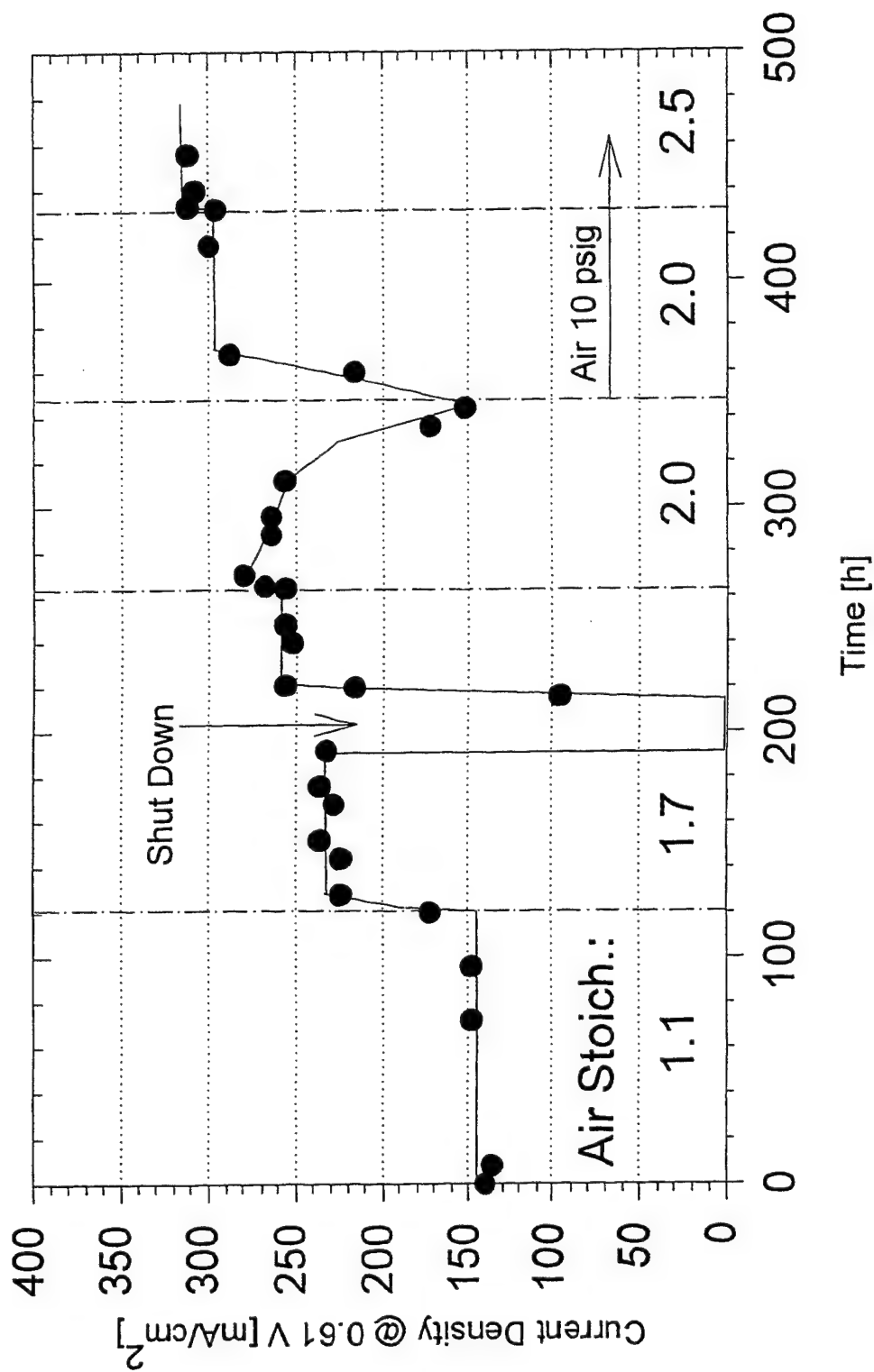
FIGURE 5
EFFECT OF AIR STOCHIOMETRY AND PRESSURE ON PEM FUEL CELL PERFORMANCE:
Increasing air stoichiometry and pressure increases cell performance.
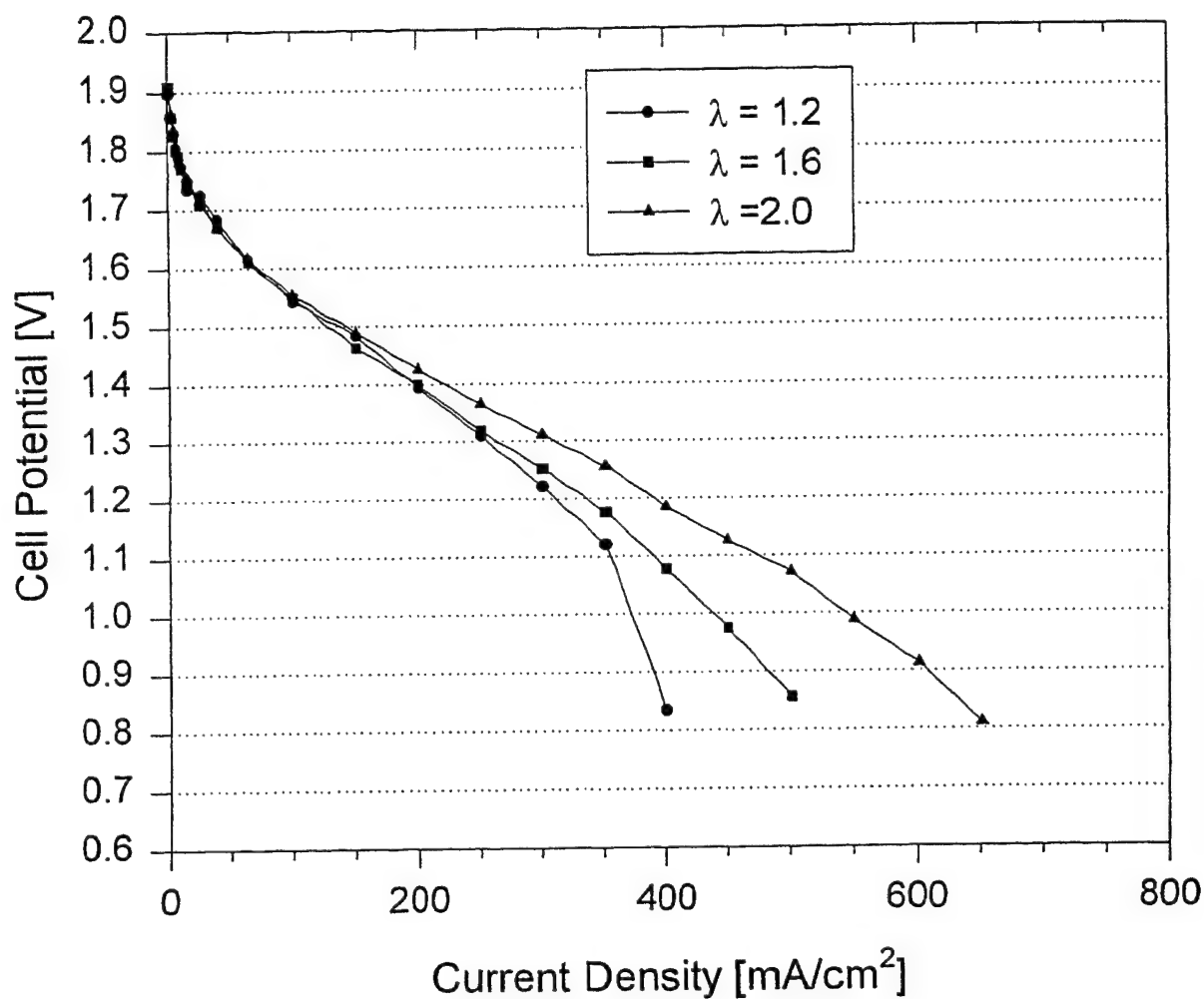
FIGURE 6
EFFECTS OF AIR STOICHIOMETRY ON PERFORMANCE
OF PEM FUEL CELL BI-CELL:
The flow rate dependence on performance is observed above 200 mA/cm²
for this bi-cell stack.
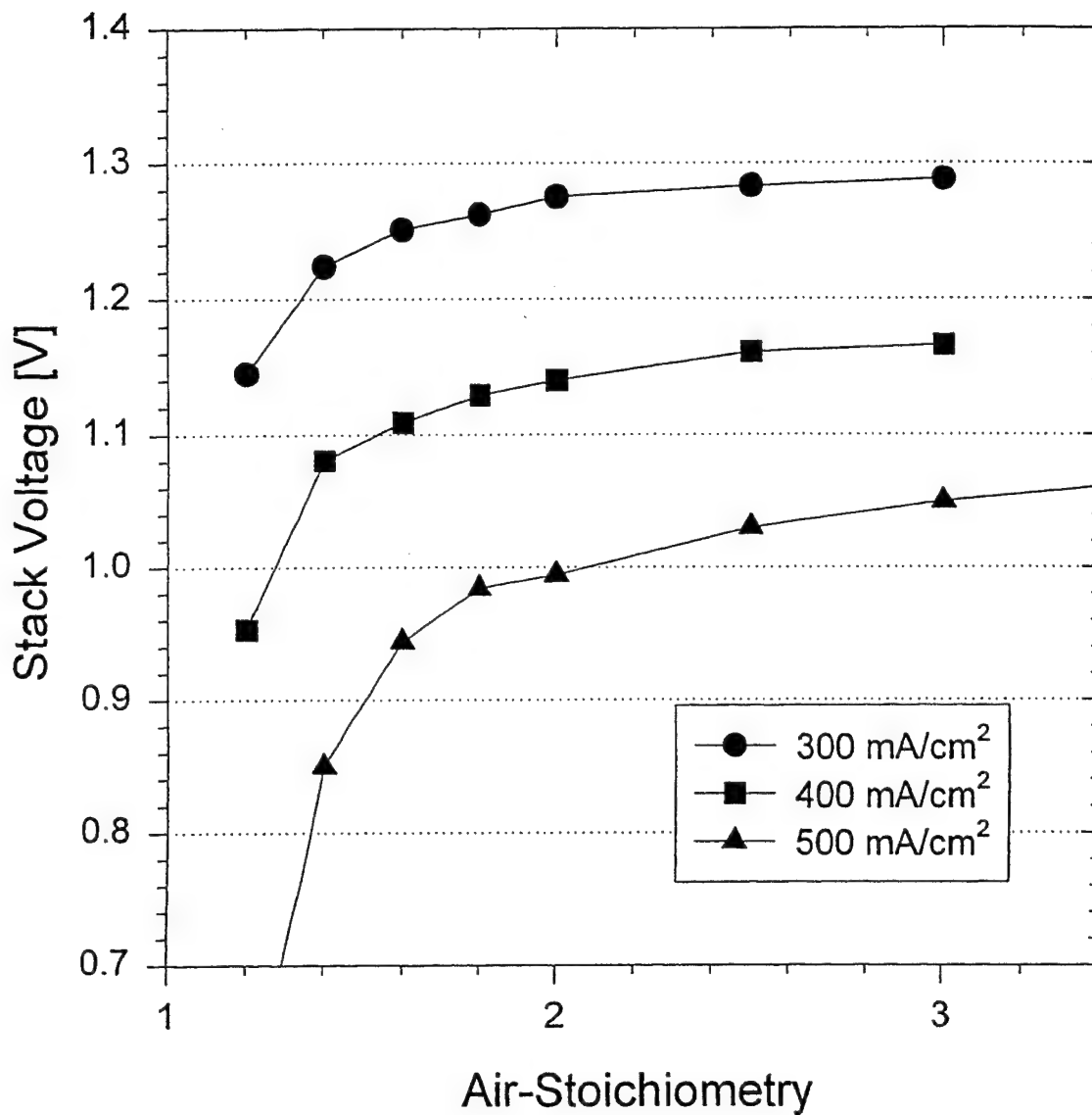
FIGURE 7
EFFECT OF AIR STOICHIOMETRY AT VARIOUS CURRENT DENSITIES:
The effect of air stoichiometry is greatest at higher current densities.
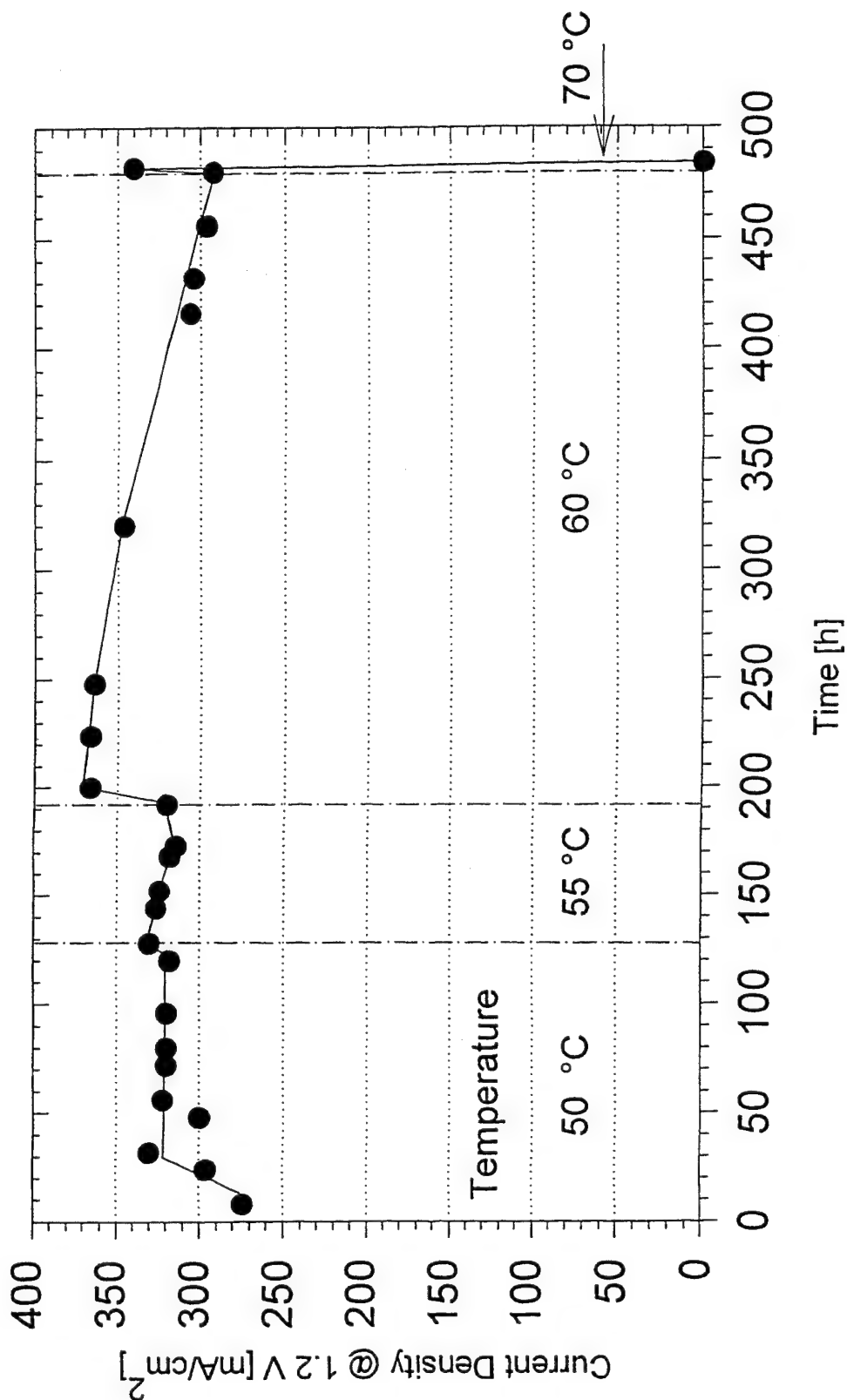
FIGURE 8

OPERATING HISTORY OF A PEM FUEL CELL BI-CELL WITOUT EXTERNAL HUMIDIFICATION: Stable performance was achieved in the 50° to 55°C operating range, however, higher operating temperatures increase performance decay.

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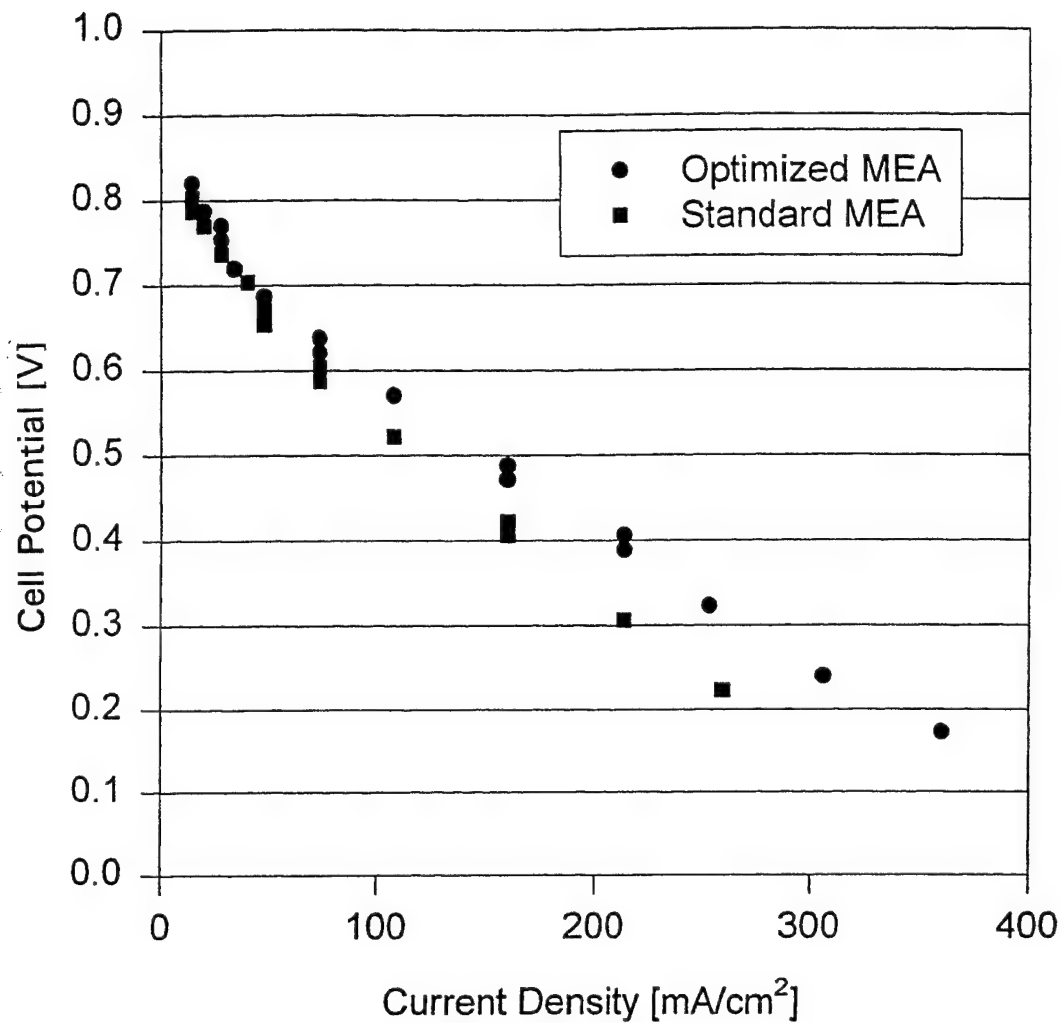
FIGURE 9
POLARIZATION CURVES FOR FUEL CELLS WITH PLASTIC PLATES (H_2/O_2):
Fuel cell performance on H_2/O_2 declines sharply with increased current density.
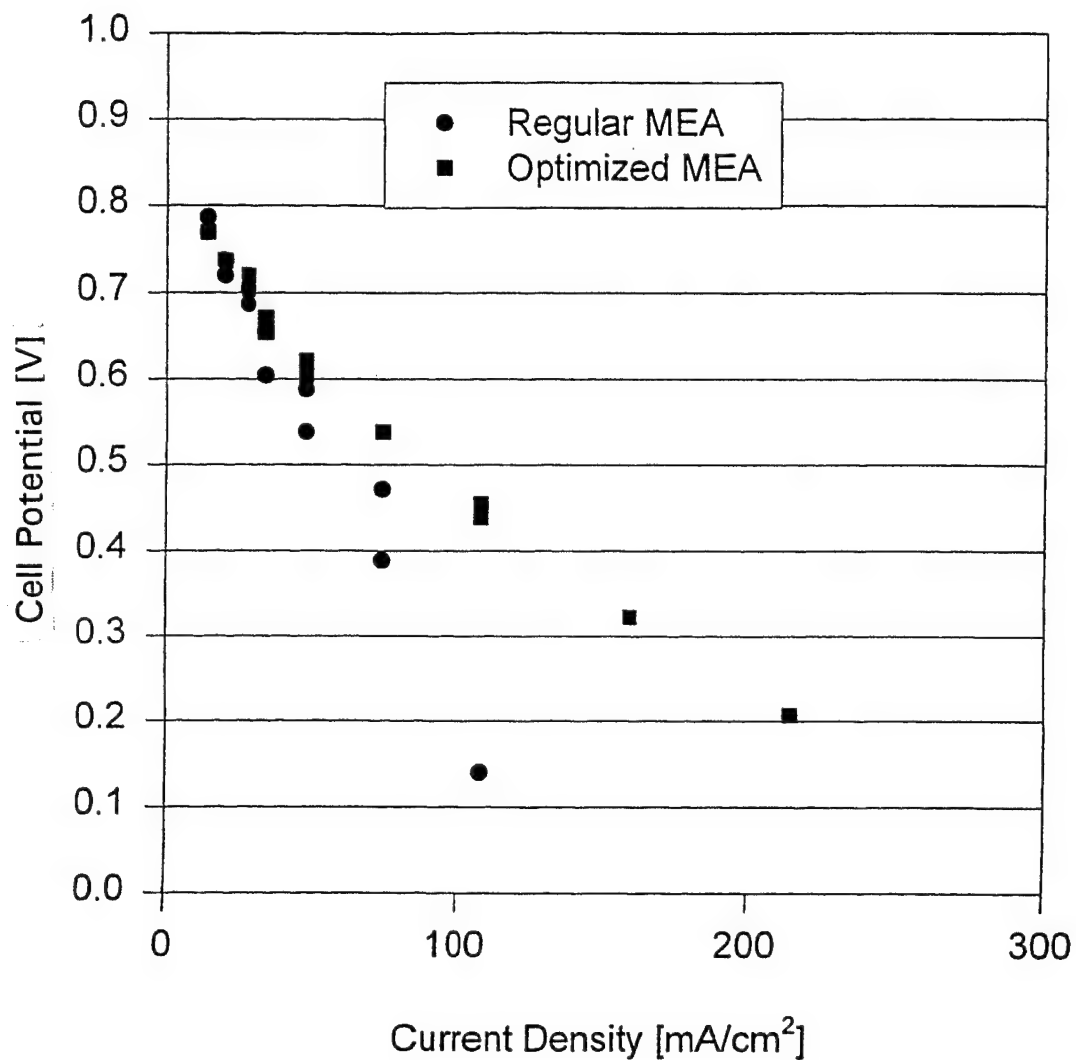
FIGURE 10
POLARIZATION CURVES FOR FUEL CELLS WITH PLASTIC PLATES (H$_2$/AIR):
Both the regular MEA cell and the optimized MEA cell show
performance less regular at higher current densities.
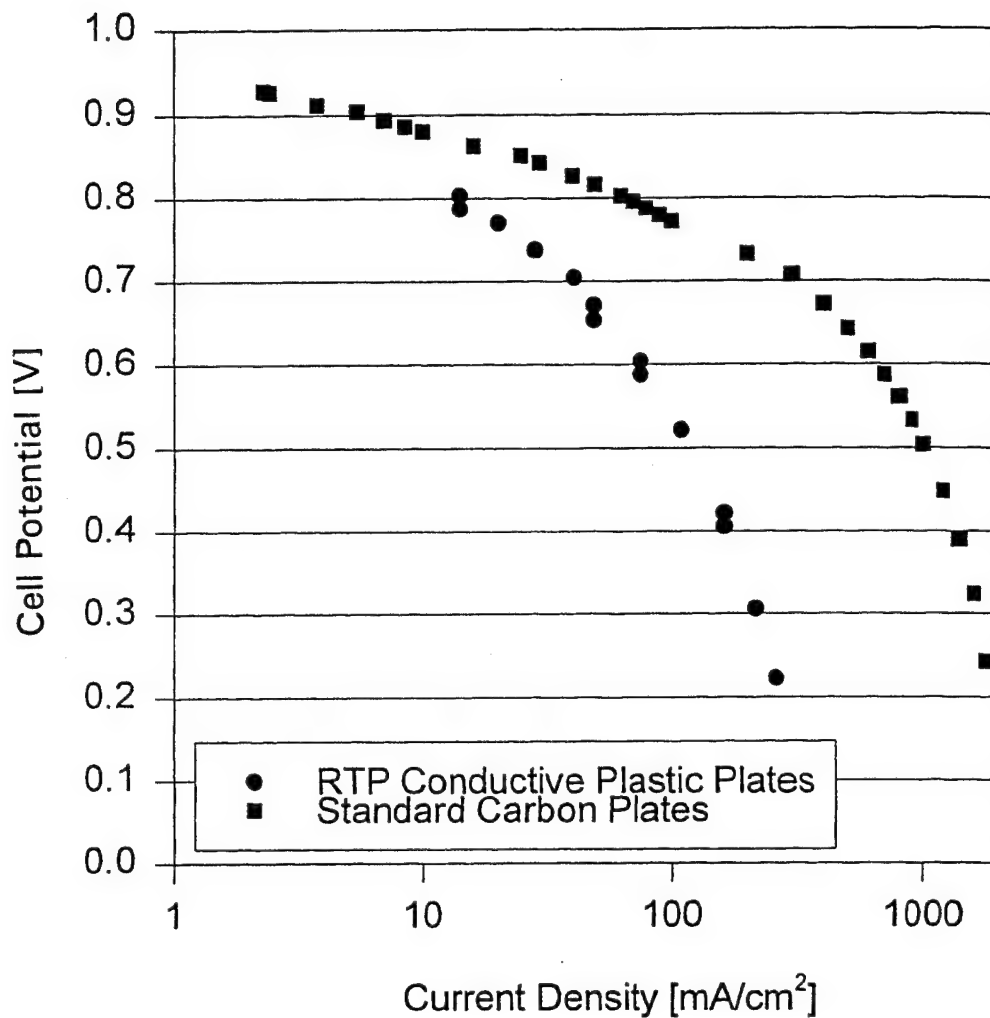
FIGURE 11
PERFORMANCE COMPARISON USING CARBON AND PLASTIC PLATES:
The lower performance of the plastic plate PEM fuel cell indicates
that lower resistitivity materials are needed.

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external humidification are quite promising. However, for satisfactory long term performances, the operating conditions need further optimization.

The conductive plastic RTP was selected for testing as current collector plates (with the fluid-flow channels) in PEM fuel cells. Two membrane and electrode assemblies were used with this conductive plastic. One was the state-of-the-art MEA with 0.4 mg Pt/cm^2 in the E-tek electrodes and Nafion 115 membrane. The other was an optimized MEA using electrodes prepared by a dry method. These electrodes were prepared with a catalytic layer of 8 mg/cm^2 mixture of 6.6 mg/cm^2 80% Pt on carbon and 1.4 mg/cm^2 teflonized (with 30% PTFE) acetylene black. The gas diffusion layer consists of 10 mg/cm^2 of teflonized acetylene black. The electrodes were brushed with Nafion 5% wt solution and hot-pressed on Nafion 115 membrane. In addition to the cell potential vs. current density measurements, cyclic voltammetric measurements and resistance measurements (using the current interruption technique) were also made. The PEM fuel cell performance plots with hydrogen/oxygen and hydrogen/air as reactants are shown in Figure 9 and Figure 10. It is clear from these figures that the slopes of these lines are extremely high. The cyclic voltammetry results indicated a relatively high roughness factor of 115 for this electrode. This result showed that the effective utilization of the platinum was quite good. The current interruption techniques showed that the main problem was the high resistance of the plastic. This is the reason for the minor differences between the PEM fuel cell performances having the optimized MEA and the standard MEA. It is clear from the semilogarithmic plot that the resistance of the plastics is the main problem. Figure 11 shows a comparison of the PEM fuel cell performance with the RTP plastics and with the graphite plates. This plot signifies the vital need for finding plastic materials with specific resistances lower by at least an order of magnitude.

3.2   Work Carried Out at Energy Research Corporation

3.2.1 Bipolar Plate Material Resistance Testing

The purpose of this work was to examine the resistivity of various candidate lightweight materials which could serve as the gas barrier layer in a composite bipolar gas distribution plate for PEM fuel cell stacks. The bipolar plate serves the following functions in the stack: (i) distribution of gases to the back side of the gas diffusion electrodes (ii) separation of anode and cathode gas streams inside the stack, and (iii) electrical connection between adjacent cells.

Materials (mainly graphite) presently used for bipolar plate manufacturing are too heavy for meeting power density targets set for vehicle fuel cells. A number of alternate materials were evaluated under this task. Both graphite and conductive plastics were candidate materials. For the gas separation layer, solid materials which have good conductivity and are not permeable by hydrogen at significant rates are candidates. For the gas distribution layers, both solid and porous materials may be

considered. A schematic of a three-piece bipolar plate assembly is shown in Figure 12. Table 3 lists the materials investigated under the Phase I effort.

A good candidate for the gas field is porous graphite. This material was tested in several thickness in combination with solid layers to determine its surface contact resistance when used in a multilayer structure. The attractive feature of porous graphite is its low density in combination with relatively good conductivity.

Resistance values for various candidate materials were obtained using the conductivity test rig shown in Figure 13. The test items were assembled between solid copper plates and placed in a press where a variable compressive force could be applied. Resistance values were obtained with a Hewlett Packard Model 4328A milliohmmeter while varying the compressive force. Table 4 lists the results of these measurements for the various materials. Since contact resistance is a major factor, the values are expressed as resistance of the 25 cm^2 sample (rather than bulk resistance).

For these series of measurements, the compressive force was limited to a range of 1 to 50 psig which was deemed to be a practical value for stack assemblies when using lightweight end compression hardware. As seen from the data plotted in Figure 14 for the 0.05 in. thick porous graphite layer, increasing the compressive force beyond 30-40 psi does not produce a significant reduction of resistance. The resistance values obtained are in the range required for use in high performance PEM fuel cells. As an example, for a 1 ft^2 cell running at 500A, a plate resistance of 0.02 milliohms results in a voltage drop of 10 mV voltage through the bipolar plate.

3.2.2 Conceptual Stack Design

Porous graphite in conjunction with a solid (impervious) graphite or conductive plastic gas separator layer can be the basis for lightweight bipolar plates for PEM fuel cell stacks. This approach can eliminate a large fraction of the plate weight, resulting in stacks which provide high specific power output at atmospheric pressure. Without pressurization, cell current densities are probably limited to about 500 amperes/square foot because of reduced electrode performance at atmospheric pressure. Lightweight stack components combined with internal humidification can more than offset the effect of the lower electrode current density on the overall fuel cell system power density.

A conceptual lightweight stack design is depicted in Figure 15. Only thin fiber or lightweight porous materials are employed. The gas flow fields are the only components which must be made thick, since they must provide for gas flow through the stack at low pressure drop. For this reason, the fields are made of porous graphite which has a very low bulk density (~ 0.4 g/cm^3 for 80% porous graphite). The thin, gas-impervious separator layer may be made of graphite, conductive plastic, or another conductive material. The porous gas flow fields allow gas diffusion to the electrodes and rejection of the product water. Based on graphitic materials, the

GAS FLOW FIELD

GAS SEPARATOR PLATE
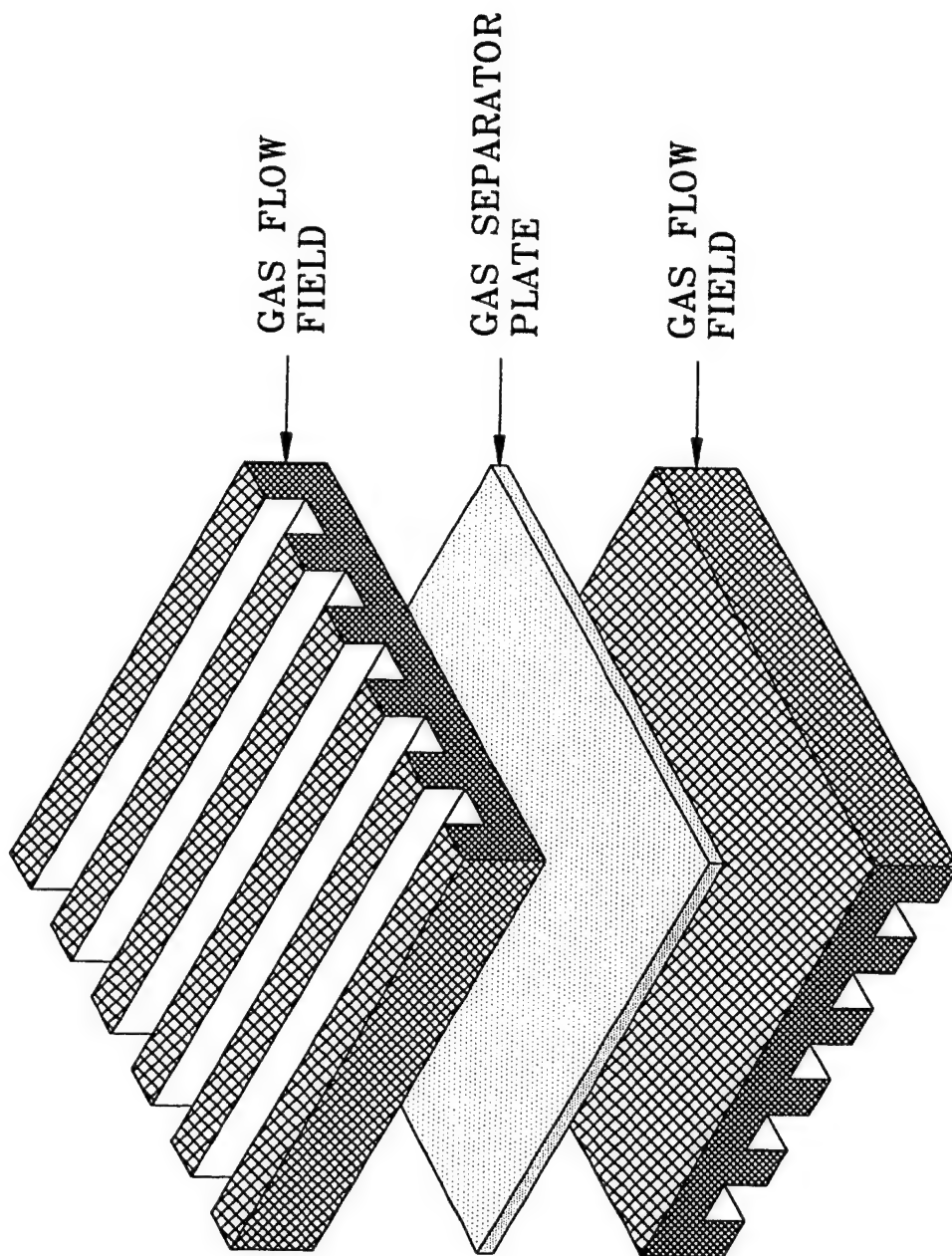
GAS FLOW FIELD

SD1412

FIGURE 12. LAYERED BIPOLAR PLATE:

Porous conductive materials may be used for gas flow field to reduce weight.

TABLE 3.   MATERIALS TESTED FOR BIPOLAR PLATE
Several materials were investigated in this effort.

MATERIAL CODE	SOURCE	DESCRIPTION
1. Graphite Plate	Energy Research Corporation Danbury, CT	0.125 inch thick molded graphite manufactured at Energy Research Corporation
2. SG-3	Showa Denko America New York, NY	0.009, 0.017 inch thick glassy carbon sheet
3. Condulon	James River Corporation Commercial Products Division Norwalk, CT	0.003, 0.004 inch thick carbon-plastic conductive film
4. TGP-510	Toray Marketing and Sales (America) Inc. New York, NY	0.050 inch thick Porosity 72% Electrical resistivity 0.15 $\Omega \cdot$cm Bulk density 0.46 g/cm^3
TGP-090	Toray	0.011 inch thick Porosity 74%, Electrical resistivity 0.15 $\Omega \cdot$cm Bulk density 0.46 g/cm^3

F

Force equivalent to 40 psi
on 2" x 2" sample

Copper Plate Size = 2" x 2"

Sample Size = 2" x 2" (25.8 cm^2)

INSULATOR
COPPER
COPPER
INSULATOR

V$\oplus$
I$\oplus$
V$\ominus$
I$\ominus$

SAMPLES
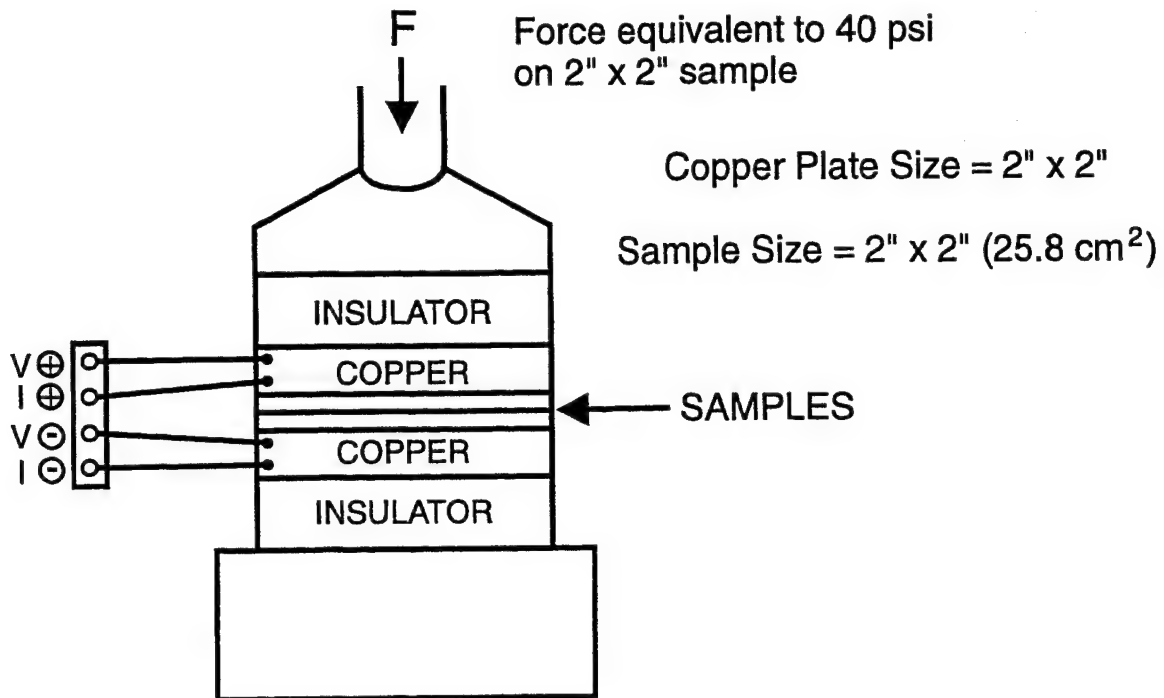
(COPPER PLATE WIRING DETAIL)

V$\oplus$

TOP

I$\oplus$

I$\ominus$

BOTTOM

V$\ominus$
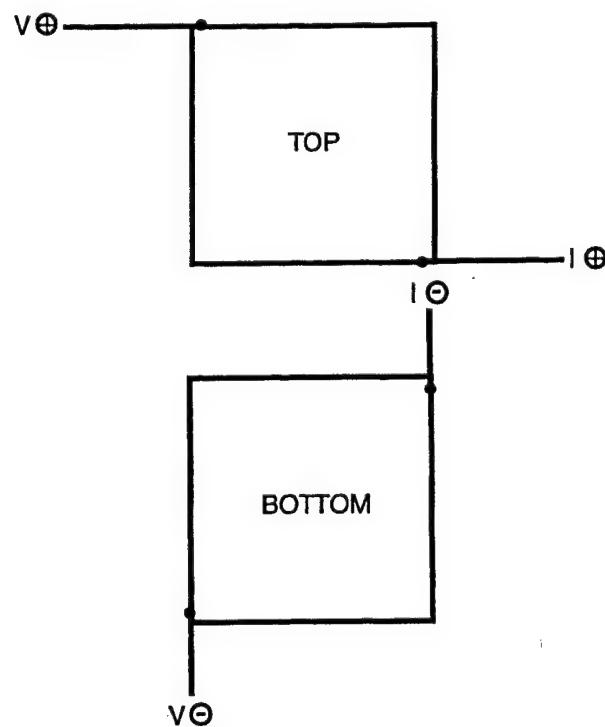
SD1411

FIGURE 13. CONDUCTIVITY TEST RIG:
Measurements were taken at various compressive forces.

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TABLE 4. BIPOLAR PLATE MATERIAL CONDUCTIVITY AT VARIOUS COMPRESSION FORCES
(Resistance in Milliohms)

Area: 25.8 cm^2

Sample psi	17 mil SD Glassy Carbon Mat-1	50 mil Toray	50 mil Toray Mat-1	11 mil Toray	11 mil Toray Mat-1	125 mil ERC Graphite Mat-1	50 mil Toray 17 mil SD Glassy Carbon 50 mil Toray Mat-1	50 mil Toray 125 mil ERC Graphite Plate 50 mil Toray Mat-1
1	5.5	8.1	6	7.6	4.2	5	5.8	10.5
5	5.5	7.4	5.5	7.3	4.15	5	5.2	8.5
10	5.5	5.6	3.5	5.7	3.9	4.5	4.2	6.5
20	3.3	3	2.05	2.35	1.9	1.9	2.7	3.4
30	2.2	2.1	1.55	1.5	1.25	1.25	2	2.65
40	1.66	1.65	1.3	1.12	1.05	1.05	1.65	2.25
50	1.41	1.36	1.15	0.91	0.9	0.88	1.45	1.95
50	1.34	1.33	1.13	0.85	0.9	0.86	1.4	1.95
40	1.35	1.37	1.15	0.92	0.9	0.86	1.45	1.97
30	1.4	1.55	1.2	1.06	0.95	0.9	1.6	2.1
20	1.54	1.97	1.35	1.4	1.05	0.98	1.8	2.4
10	1.92	3.1	1.65	2.4	1.25	1.15	2.35	3.05
5	2.16	4.6	2.05	3.7	1.45	1.3	3.1	4.2
1	2.54	5.2	2.4	4.4	1.75	1.5	3.9	5

TABLE 4. BIPOLAR PLATE MATERIAL CONDUCTIVITY AT VARIOUS COMPRESSION FORCES (Continued)

(Resistance in Milliohms)

Area: 25.8 cm^2

Copper Test Fixture	Mat-1	Mat-1 Mat-1	Mat-1 Mat-1 Mat-1	Mat-1 3 mil Condulon Mat-1	Mat-1 4 mil Condulon Mat-1	9 mil SD Glassy Carbon	Mat-1 9 mil SD Glassy Carbon Mat-1
0.02	2.75	4.1	5	63	46	30	72
0.02	2.75	4.1	5	50	46	23	26
0.02	2.55	4.1	4.8	15	18.5	17.5	7.6
0.01	1.8	2.85	3.1	14.6	6.7	8.2	3.22
0.01	1.16	1.84	2.3	10.5	4	5.2	2.1
0.005	0.94	1.46	1.93	8.7	3.2	3.7	1.65
0.005	0.81	1.3	1.71	2.2	2.6	3	1.35
0.005	0.77	1.24	1.66	2.05	2.4	2.9	1.32
0.005	0.78	1.25	1.66	2.1	2.42	3.1	1.35
0.005	0.82	1.28	1.74	2.43	2.5	3.7	1.45
0.01	0.92	1.44	1.89	2.55	2.8	5.1	1.65
0.01	1.16	1.7	2.23	3.3	3.3	8.2	2.4
0.02	1.43	2.1	2.6	4.1	3.9	13.5	3
0.02	1.56	2.2	2.74	4.8	4.2		3.3

Material: 0.050" porous graphite (Toray)
AREA: 25.8 cm²
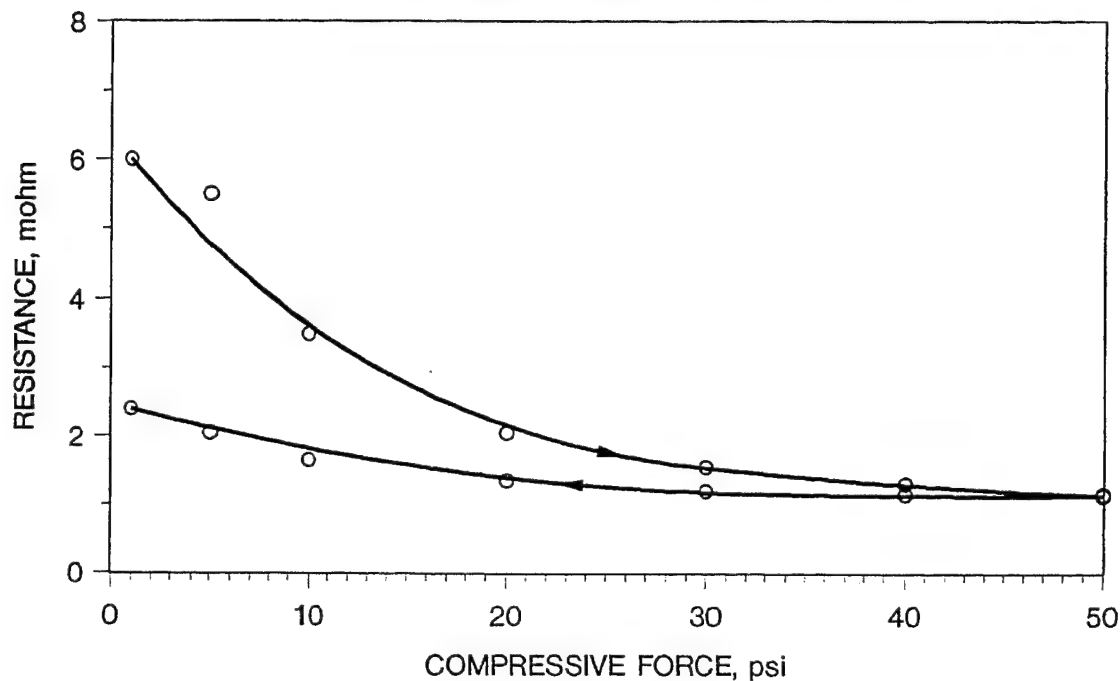
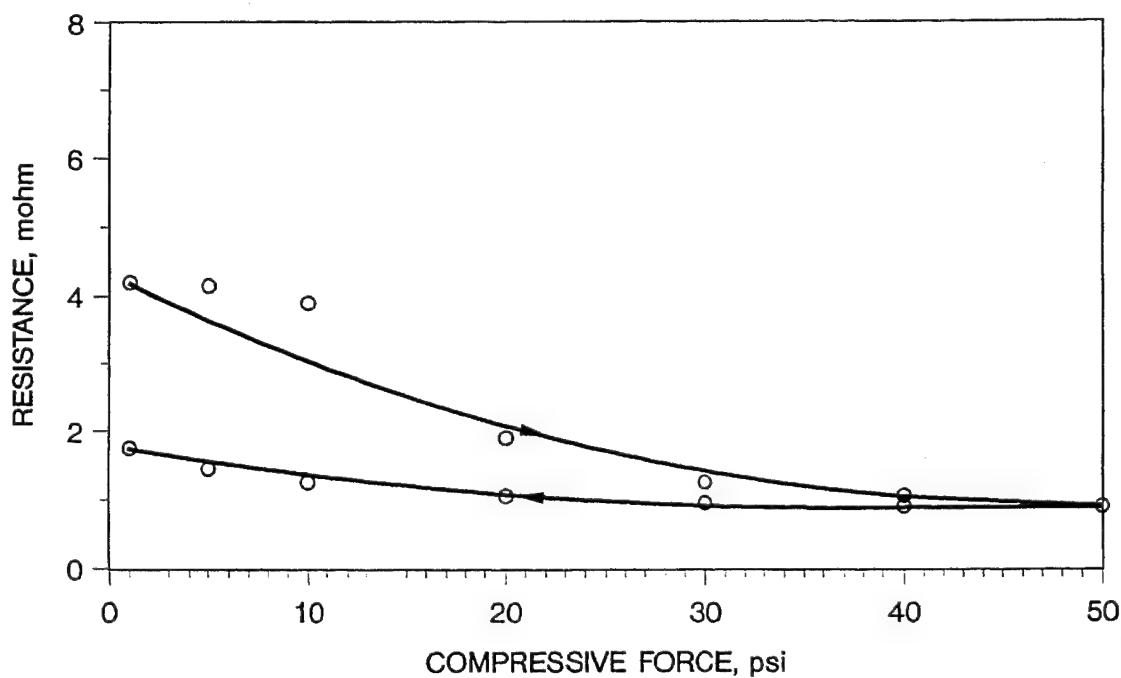Material: 0.011" porous graphite (Toray)
AREA: 25.8 cm²

FIGURE 14
EFFECT OF COMPRESSION ON RESISTANCE
Increasing the pressure beyond 30 psi does not
significantly affect the sample resistance.

COMPONENT	THICKNESS, in.	WEIGHT	
		g/ft²	g/Kw
1. MEMBRANE	.002	10.0	33.3
2. CATALYST LAYER .3 gPt/ft²	.003	4.0	13.3
3. POROUS GRAPHITE FLOW FIELD	.050	23.6	78.7
4. SEPARATOR PLATE	.005	11.6	38.7
5. POROUS GRAPHITE FLOW FIELD	.050	23.6	78.7
6. CATALYST LAYER .2 gPt/ft²	.002	3.0	10.0
	.112	75.8	252.7

SD1404C

FIGURE 15. SINGLE CELL TEST FIXTURE:

Only thin film or lightweight porous materials are used. At 500 ASF and 0.6 VDC, the repeating stack components in one cell weigh only 0.25 kg/kW which is approximately 10% of the DOE target of 2.5 kg/kW.

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repeating components have a total weight of 76 grams/square foot. Assuming a power density of 300 W/ft^2 (500 ASF @ 0.6 VDC), these components weigh only 0.6 lb/kW. End plates, external manifolds, and cooling plates will, of course, bring the total stack weight up to a higher value. Nevertheless, the DOE electric vehicle fuel cell power density goal of 5.5 lb/kW appears to be eminently achievable with this stack construction concept.

3.2.3 Single Cell Testing

Single cells were built and tested with hydrogen fuel and oxygen or air as the oxidizer. The flow fields used in these cells were porous graphite with machined flow channels. The cells had an active area of 0.1 ft^2 ($\sim$ 100 cm^2) and were operated at atmospheric pressure.

Cell polarization data along with construction and test parameters for the single cell tests are shown in Figure 16. Both ERC and E-tek electrodes with platinum loading of 0.3 to 0.4 g/ft^2 were used. Stable performance was achieved at about 300 ASF and 0.6 VDC. This performance level will be improved in the future by reducing cell resistance and increasing electrode activity.

3.2.4 Evaluation of Cell Subassemblies Prepared by TAMU

Several membrane electrode assemblies (MEAs) prepared at TAMU were evaluated at ERC. These assemblies were designed for operation without external humidification. In tests at ERC, they were evaluated both with and without external humidification, and at atmospheric as well as elevated pressures. Representative cell polarization data obtained with the TAMU MEA is shown in Figure 17.

4.   CONCLUSIONS AND RECOMMENDATIONS

One of the main accomplishments in Phase I was that several plastic manufacturers were contacted, some sample materials obtained, and these materials were characterized in respect to their specific resistances. There were at least two conductive plastic materials with specific resistances of between 0.5 and 0.8 ohm/cm. There could be further modifications of the surface by either hot-pressing carbon cloth or by depositing a thin metallic layer on the plastic to overcome the contact resistance problem between the plastics and the membrane and electrode assemblies. During the short reporting period, it was not possible to incorporate a metal gauze or mesh in the plastic. This could further decrease the specific resistance significantly. A further major accomplishment in Phase I was the optimization of the structure and composition of the membrane and electrode assemblies to operate PEM fuel cells without external humidification. This is a great advantage because water management is one of the most significant challenges in PEM fuel cell technology. A PEM fuel cell, operating without external humidification, could considerably decrease the weight of the PEM fuel cell stack.

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CELL NO. 81

Active Area: 100 cm²
Membrane: NAFION N112
Electrodes: ERC .3 mgPt/cm²
Cell Temp.: 72 °C
H₂ 1.3 x, 1 ATM, 50°C HUM.
AIR 9 x, 1 ATM, 66°C HUM.
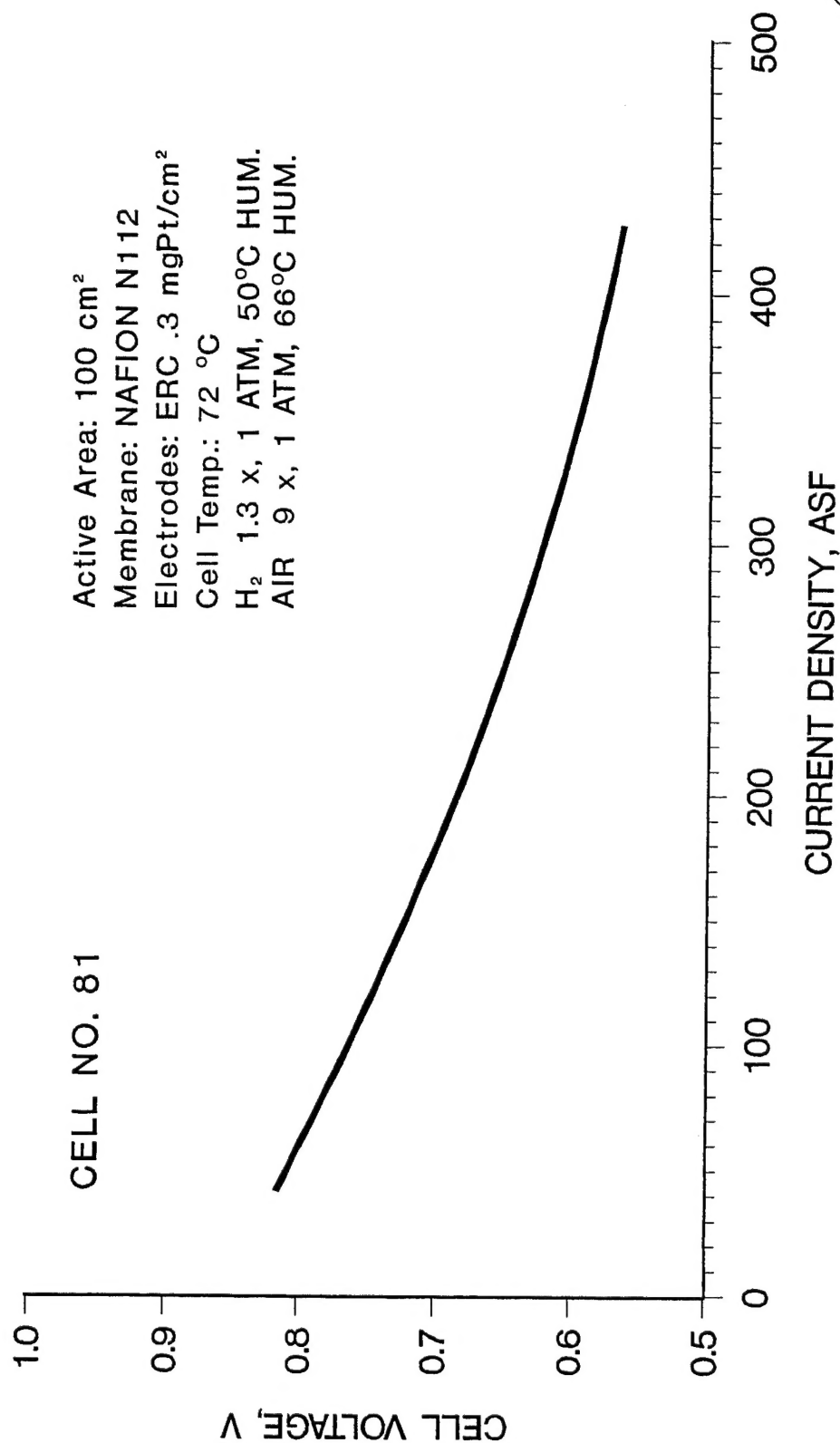
FIGURE 16
CELL POLARIZATION DATA WITH LIGHTWEIGHT CELL COMPONENTS:
Stable performance was achieved at ~ 300A/ft² and 0.6 volts.

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CELL NO. 80

Active Area: 40 cm²
Cell Temp.: 50°C
H₂ 1.3 X, 50°C HUM.
O₂ 1.5 X, 60°C HUM.

30 psig

1 ATM

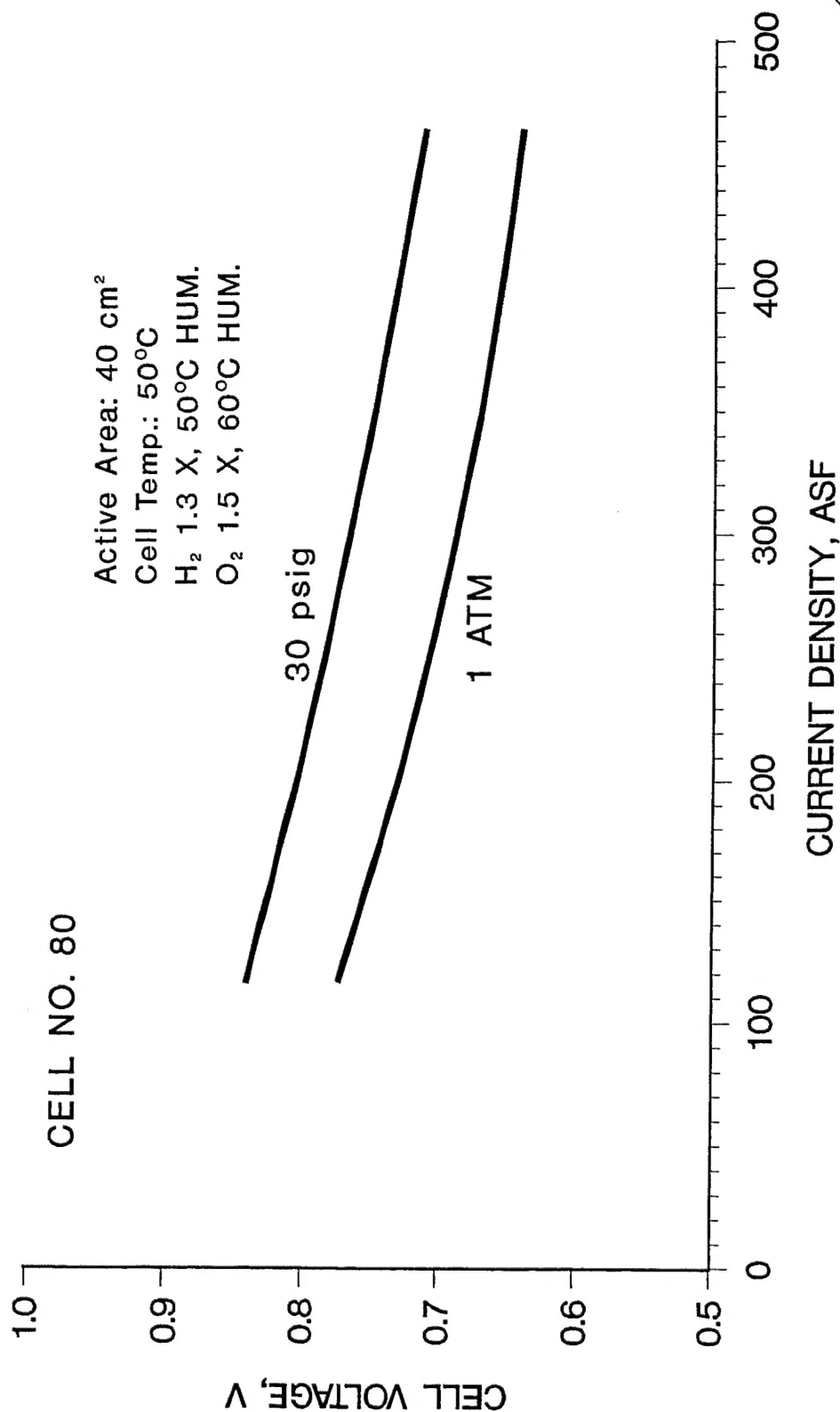CELL VOLTAGE, V

CURRENT DENSITY, ASF

SD1417

FIGURE 17

SINGLE CELL PERFORMANCE WITH TAMU ELECTRODE MEMBRANE ASSEMBLIES:
Stable performance was achieved at both atmospheric and pressurized conditions.

5. PROPOSED TASKS FOR PHASE II

The objectives of Phase I of the proposed project included development of low-cost, lightweight materials for components of proton exchange membrane fuel cells (PEM fuel cells), which are being considered for electric vehicle power plants and other widespread applications. To comply with the requirements for widespread use of vehicle fuel cells, two of the main goals of Phase II of this project are to use electrodes with ultra-low platinum loadings (7), and to use advanced proton exchange membranes which allow higher performance than those currently available, without sacrificing mechanical properties. The developers of these advanced membranes predict low manufacturing costs in large quantities. PEM electrolytes require the presence of water for proton conduction. In most work, this is supplied by humidification of reactant gases via a complex subsystem. Another goal is to operate the fuel cell components with internal humidification at low operating pressures, preferably 1 atmosphere absolute (atma) or slightly above, as demonstrated in Phase I. Today, the heaviest cell repeating component is the bipolar plate. The development of a low-cost bipolar plate using inexpensive, lightweight materials is also part of the Phase II program. The project will involve a team consisting of Energy Research Corporation, Danbury, CT, a small business and a major developer of fuel cells, a university research center (the Center for Electrochemical Systems and Hydrogen Research, CESHR, Texas A&M University, TAMU), and another small business (BCS Technology, Inc., Bryan, TX, a spin-off of CESHR). Expected accomplishments in Phase II are: (i) identification of low-cost materials and fabrication techniques for cell stack components; (ii) demonstration of a high level of performance with ultra-low platinum loadings, internally humidified operation; (iii) novel concepts for thermal and water management; (iv) development of a 4 to 6 cell short stack with the desired electrode areas for the transportation application; and (v) design concepts for a fuel cell power plant for an electric vehicle to be constructed in Phase III.

6. REFERENCES

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